A Model for Near-Surface Groundwater on Mars

Kelly J. Kolb[1], Herbert V. Frey[2], Susan E.H. Sakimoto[3]

[1] 2003 NASA Academy R.A., B.S. Candidate Astronomy and Astrophysics, Villanova University, Villanova, PA 19085, kelly.kolb@villanova.edu

[2] P.I. Geodynamics Branch, Code 921, NASA Goddard Space Flight Center, Greenbelt, MD 20771, herbert.v.frey@nasa.gov

[3] GEST at the Geodynamics Branch, Code 921, NASA Goddard Space Flight Center, Greenbelt, MD 20771, sakimoto@geodynamics.gsfc.nasa.gov

Objective

To use a model of near-surface ground water on Mars to study gully formation and near-surface lava-ice interactions.

Introduction

Since Percival Lowell first described his observations of the "canals of Mars" as irrigation ditches on a dying planet, people have dreamed of life on Mars. A key ingredient to such life is water. Mars may have been a warmer, wetter planet in the past, but today it appears to be cold, dry, and biologically dead. However, there may be places beneath the surface where life can exist, an idea supported by observations that suggest water at depth.

The Gamma Ray Spectrometer (GRS) aboard the Mars Odyssey Mission has returned large amounts of data mapping the distribution of epithermal and thermal neutrons across Mars, up to one meter below the surface. Epithermal neutrons are neutrons that are slowing to thermal velocities, while thermal neutrons exist in the regolith waiting to be absorbed (http://grs.lpl.arizona.edu/results/pressconf1/). The Hydrogen atom, being of similar to size to the neutron, is very efficient at creating thermal neutrons, so where large amounts of Hydrogen are present, few fast moving or epithermal neutrons exist, represented by the blue color in Figure 1 (2002Sci…297…78M).

The GRS only accounts for the H distribution in the top meter of the Martian regolith. Since Mars, even though currently dry, likely had a wet past, there is a great possibility that water exists beneath the surface, much deeper than one meter. There are many geological features on Mars that suggest liquid water once existed on the Martian surface. However, the present-day surface temperature and obliquity (the tilt of the Martian equator with respect to its orbital plane) of Mars are not suitable for liquid water. The obliquity of Mars varies in timescales on the order of 10^5 years and ranges between 11 and 40° (2001JGR…10623165M).

Gullies observed in high resolution pictures are one of the most important geological features on Mars that may indicate the presence of liquid water on Mars within geologically recent timescales (2000Sci…288.2330M). The mechanism for gully formation is unknown, but ground water seepage is the leading candidate. Gullies are found in many locations of Mars, some of which have abundant near-surface Hydrogen (water) but also many of which are depleted in Hydrogen and believed to be dry. Thus in some areas there is apparent evidence for a recent water table at depth but no present-day near-surface concentration of water.

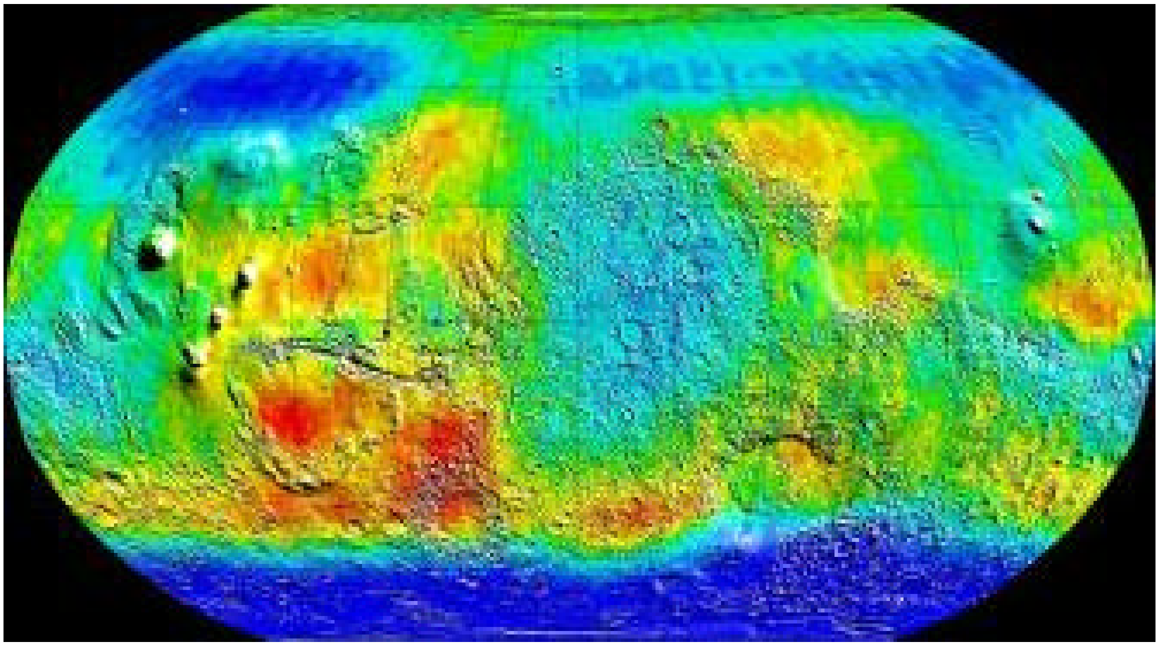

Figure 1. Epithermal Neutron Distribution
Blue: few neutrons, abundant Hydrogen
http://grs.lpl.arizona.edu/results/presscon2/

A way to help solve the puzzle of gully formation is to determine the subsurface ground water distribution on Mars. The past and present-day distribution of ground water depends on a large number of factors, and models have been created to account for these. The most sophisticated of these models were published by Mellon & Jakosky (1993JGR…98.3345M [MJ93], 1995JGR…10011781M [MJ95], 1997JGR…10219357M [MJP97]).

We wish to use such models to investigate particular situations where water may have persisted over long time periods, as well as situations where ground water may have become depleted in geologically short times. We are primarily interested in understanding how a steady-state reservoir of ice (one occurring at depth z below that surface that loses water vapor to the atmosphere at the same rate that it is replenished by a water supply from below) could lead to gully formation. We are also interested in understanding how volcanic lava flows overlying the aforementioned steady-state (SS) ice layer can affect the presence of ice, perhaps forcing it out of the surface at depths on the order of 100s of meters, precisely the depth at which gullies are found. We are also interested in the timescales on which such layering, melting, outflow, and atmospheric exchange take place.

My Contributions
- research and study Martian ground water models
- examine equations and parameters used in models
- reproduce models using IDL programming language
- (expected) run models to get subsurface water distribution for various regions of Mars
- (expected) relate water distribution results to geological features, especially gullies and recent lava flows

Gully Observations
2000Sci…228.2300M

Gullies are found:
- preferentially poleward facing (~2.5:1) rather than equatorward facing
- at mid to high latitudes, ~ 30 to 70 °N and S
- with shallow depths of origin, top ~ 100 to 500 meters of slopes
- to be geologically young (20 yr to 1 Myr)
- in a variety of topographical features:
    - -- simple scarps
    - -- mesas
    - -- knobs
    - -- crater walls (see Figs. 2 & 3)
    - -- central peaks

Figure 2. Gullies in Newton Basin at 39.0°S, 166.1°W
http://mars.jpl.nasa.gov/mgs/msss/camera/images/june2000/

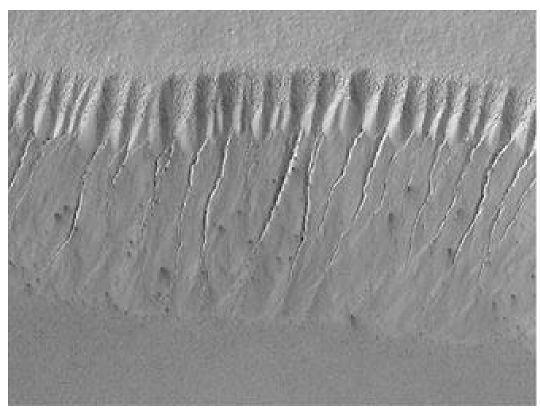

Figure 3. Gullies at 70.7°S, 355.7°W
http://mars.jpl.nasa.gov/mgs/msss/camera/images/june2000/

Gully Shape (see Fig. 4):
2003Natur.422…45C
- A source region: alcove ~ 200 m wide
- V-shaped channels leading from the alcove: ~ 100 m wide
- Depositional Fan Apron
- typical dimensions: 20 m wide, 500 m long, 10 m deep

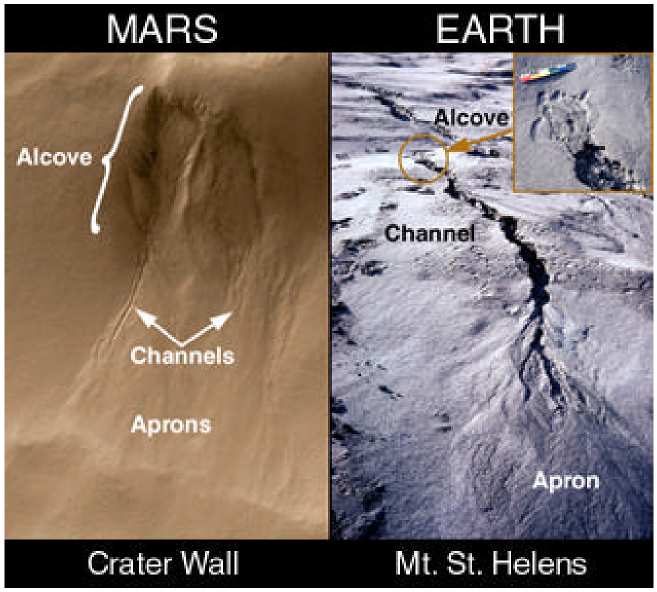

Figure 4. Gully located at 54.8°S, 342.5°W
Area = 1.3 km wide, 2 km long
http://mars.jpl.nasa.gov/mgs/msss/camera/images/june2000/

The Model

Michael Mellon, Bruce Jakosky, and co-authors have developed models to map the distribution of subsurface water on Mars (MJ93, MJ95, MJP97).

MJ93 explores water within the top few centimeters of the surface. In this model condensation of water from the atmosphere is the only source of water in the regolith. This model ignores the effect of CO_2 driven water vapor transport through the regolith. It includes geographic variations in albedo and thermal inertia (the ability of a material to resist changes in temperature). It does not include a geothermal temperature gradient near the surface of Mars. MJ93 describes a Thermal Diffusion (TD) model and a Molecular Diffusion (MD) model which are used in MJ95 and MJP97.

Thermal Diffusion (TD) Model

Thermal diffusion "is the transfer of gas caused by a temperature gradient separate from all other gradients and results from momentum exchange between molecules of different mass" (MJ93). The TD Model assumes that the surface is vertically homogeneous and that surface thermal and physical properties remain constant over 10^5 year timescales. It includes latitudinal changes in insolation, solar heating effects, atmospheric thermal radiation on the surface, and seasonal CO_2 frost. It ignores any geothermal flux and long-term time dependent effects of subsurface thermal properties and behavior of CO_2 frost. This model calculates the vapor saturation density, the mean average surface temperature, and the subsurface temperature as a function of depth z for 2° by 2° latitude x longitude boxes between 60 °N and 60 °S.

Molecular Diffusion (MD) Model

The MD Model provides equations for molecules of water vapor diffusing through CO_2 gas. It accounts for Normal and Knudsen diffusion. In Normal Diffusion, gas-gas collisions dominate. Knudsen Diffusion occurs when gas molecule-pore wall collisions dominate. Knudsen Diffusion is dependent on soil pore geometry. Straight round pores are assumed.

The MD model assumes a regolith completely devoid of water. It does not account for diurnal surface temperature changes. It assumes that the top layer of the ice table interacts with the atmosphere while the bottom layer lies above a nonporous layer. It calculates the ice content of the Martian regolith as a function of time and depth.

MJ95 expands MJ93 by using a spatially variable atmospheric water content. The atmospheric column abundance of water is determined as a function of Mars' obliquity.

MJP97 offers two models, a Non-Equilibrium (NEq) Model and a Steady-State (SS) Model. The NEq Model assumes that the regolith is initially saturated with ice down to 200 meters and that there is no resupply of water from a deeper source.

The SS Model maps the distribution of ice forming a steady-state layer a depth z below the surface of Mars (see Fig. 5). A steady-state layer theoretically lasts indefinitely because the amount of water lost to the atmosphere through diffusion and sublimation is being balanced by water diffusing and recondensing from a deeper water supply. We are interested in determining how such a layer reacts to the presence of molten lava above it and the timescales over which it might become completely desiccated. The SS Model uses the diffusion coefficient, D, and the porosity, e, determined from MJ93. Since the thermophysical properties of the Martian regolith are mostly unknown, the authors of MJP97 compute the depth, z_0, and the temperature, T_0, for three types of regolith material. The values we choose fit a particulate composition. See Table 1 for our Model Parameters.

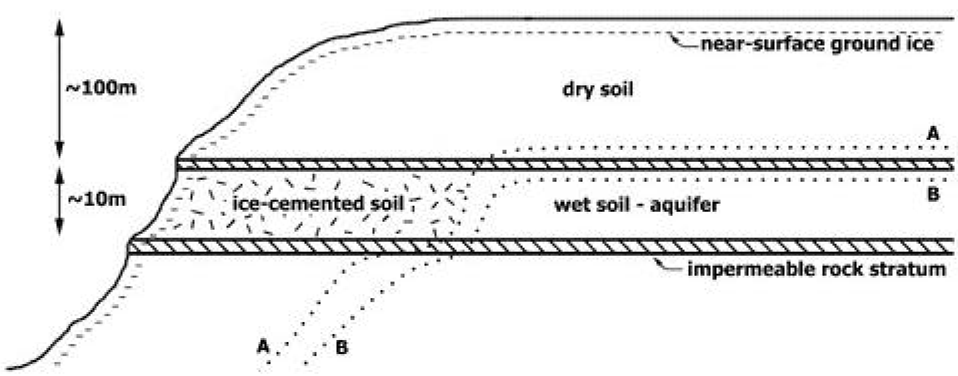

Figure 5. Model of Trapping and Freezing Groundwater leading to Gully Formation
A & B: Melting Isotherms at different obliquities
2001JGR...10623165M- Fig. 11

Table 1. Model Parameters

Symbol	Parameter	Value	Units	Ref
T_s	Mean surface temperature	220	K	1
ε	Porosity	0.4		2
ρ	Bulk regolith density	1680	kg/m^3	1
dT/dz	Geothermal temperature gradient	0.15	K/m	1
θ	Obliquity*	25.19	Degrees	2
y_v	Water vapor mixing ratio	0.0003		3
r	Mean pore radius	10	pr µm	1
C	Specfic heat of dry soil	837.36	J/kg K	1
τ	Tortuosity	3		1
P	Ambient surface pressure	610	Pascals	1
n_{atm}	Atmospheric vapor density*	10	pr µm	1
k_0	Ice free thermal conductivity	0.3	W/m K	4

* of present day Mars
Refs: 1. MJ93, 2. MJ95, 3. http://laserweb.jpl.nasa.gov/planetaryinstruments/mirls.html, 4. MJP97

Future Plans

We plan to explore a range of parameters corresponding to particular situations of interest. Examples include a thick ice layer (10s of m) at substantial depth (100s of m) and a water-rich near-surface layer overlain by a recent (hot) lava flow. We are interested in determining how a steady-state ice layer reacts to the presence of molten lava above it and the timescales over which the overlying regolith might become completely desciccated. Another aspect we will consider is what occurs when lava-ice-lava-ice layering is found.

Acknowledgements

- Delaware Space Grant Consortium
- GSFC Geodynamics Branch, Code 921
- NASA Academy Program Staff
- Family and Friends
- Villanova University Astronomy Dept.

References

Boynton, W.V. et al. *Distribution of Hydrogen in the Near Surface of Mars: Evidence for Subsurface Ice Deposits*. 2002, Science, 297, p. 81-85.

Christensen, P.R. *Formation of recent Martian gullies through melting of extensive water-rich snow deposits.* 2003, Nature, 01436.

Malin, M.C. and Edgett, K.S. *Evidence for Recent Groundwater Seepage and Surface Runoff on Mars*. 2000, Science, 288, p. 2330-2335.

Mellon, M.T. and Jakosky, B.M. *Geographic Variations in the Thermal and Diffusive Stability of Ground Ice on Mars*. 1993, JGR, 98, E2, p. 3345-3364.

Mellon, M.T. and Jakosky, B.M. *The distribution and behavior of Martian ground ice During past and present epochs*. 1995, JGR, 100, E6, p. 11781-11799.
Mellon, M.T., Jakosky, B.M., and Postawko, S.E. *The persistence of equatorial ground ice on Mars*. 1997, JGR, 102, E8, p. 19357-19369.
Mellon, M.T. and Phillips, R. J. *Recent gullies on Mars and the source of liquid water.* 2001, JGR, 106, p. 1-15.